DESIGNING A LAB-SCALE WATER TREATMENT PLANT

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Abstract-- *A major objective of the Junior and Senior Engineering Clinics at Rowan University is to introduce students to open-ended design projects. The purpose of the clinic classes is to provide engineering students with a hands-on, multidisciplinary experience throughout their college education. This type of innovative approach for allowing students to become involved in realistic open-ended design problems is beneficial for enhancing their problem solving skills and encourages them to pursue graduate studies. This paper focuses on the design and development of a laboratory scale water treatment plant for enhancing student learning and understanding.*

A multidisciplinary student team conducted a thorough literature search and developed an innovative mobile laboratory scale water treatment plant. This plant can be used in various environmental and chemical engineering courses to reinforce unit operations in water treatment. The project focused on treating raw surface water and converting it into potable water by conventional water treatment processes, such as sedimentation, filtration, activated carbon adsorption, ion exchange, and disinfection. Water quality is characterized by standard parameters such as Suspended Solids (SS), Total Solids (TS), Conductivity, pH, Hardness, Turbidity, Chemical Oxygen Demand (COD), Total Organic Carbon (TOC), Nitrate and Fecal Coliform Bacteria. Visual observations along with water quality measurements helps in better understanding of each treatment process. Students are required to calculate conventional design parameters and efficiency of each treatment process. Course evaluations indicate that students have a better understanding of the design of a water treatment plant and its unit operations.

Index Terms: unit operations, water treatmen,

INTRODUCTION

Most conventional unit operations or process design courses in chemical and environmental engineering have laboratory components. These laboratories primarily focus on introducing students to relevant unit operations to their course materials. Topics that are common in both chemical and environmental unit operations are indicated in Table 1.

Table 1: Unit Operations Topics

Sedimentation/Clarification/Settling
Filtration
Adsorption
Ion-exchange
Disinfection

Most of these common processes are demonstrated typically through individual laboratory experiences. Field trips are also typically included to enhance student learning and understanding of the operation of all these unit processes in a water/wastewater or chemical processing plant. This paper describes the development of a lab-scale mobile water treatment plant to demonstrate a number of unit processes. The objectives of teh development of this lboratory scale plant were as follows:

- Enhance student learning and understanding of unit processes in a realistic context,
- Demonstrate major water treatment processes and relevant operational parameters,
- Relate water quality parameters for determining efficiency of each unit process,
- Evaluate water quality parameters for determining federal and state regulatory compliance, and
- Calculate relevant design parameters such as loading rates, detention time, chemical dosages etc.

A multidisciplinary student team was asssigned to design the mobile laboratory scale water treatment plant. This team participated in the upper level engineering clinic class to develop the design and fabricate the plant. A major objective of the Junior and Senior Engineering Clinics at Rowan University is to introduce students to open-ended design projects. The purpose of the clinic classes is to provide engineering students with a hands-on, multidisciplinary experience throughout their college education. This type of innovative approach for allowing students to become involved in realistic open-ended design problems is beneficial for enhancing their problem solving skills and encourages them to pursue graduate studies.

PLANT DESIGN

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The student team identified the following tasks for the assigned project:

1. Locate source of water to be treated,
2. Identify water quality parameters to be tested
3. Analyze and characterize source water quality
4. Identify unit operations,
5. Design reactors (diameter, height),
6. Identify realistic values of operating parameters such as flowrate, chemical dosages, detention time etc.,
7. Order supplies, structure and various parts for assembly,
8. Construction and operation of water treatment plant, and
9. Prepare technical report on operating procedures.

The student team also faced a number of design challenges. The plant design was subject to the following constraints:

- Footprint area no greater than 12 ft^2
- Height not exceeding 8 feet
- Mobility for classroom demonstrations, engineering openhouse demonstrations and outreach activities
- Low maintenance and easy to operate
- Sturdy
- Cost not exceeding $3,500

The Rowan Pond adjacent to the College of Engineering was identified as the source of raw water. This pond is fed by the Chestnut branch of the Mantua Creek in New Jersey. The raw water was collected in a 180-liter drum. Alum (Aluminum Sulfate) and Magnesium Sulfate were added to enhance particle coagulation and flocculation. Water quality parameters identified for testing are presented in Table 2.

Table 2: Water Quality Parameters

Conductivity, pH, Turbidity, Color
Solids (Total and Suspended)
Hardness, Alkalinity
Organics (TOC, COD)
Bacteria (Total Fecal Colifirm, Presence and Absence Test)

Treatment processes identified for design were as follows:

- Sedimentation
- Filtration
- Adsorption
- Ion-exchange
- Disinfection

A preliminary design process diagram is shown in Figure 1:

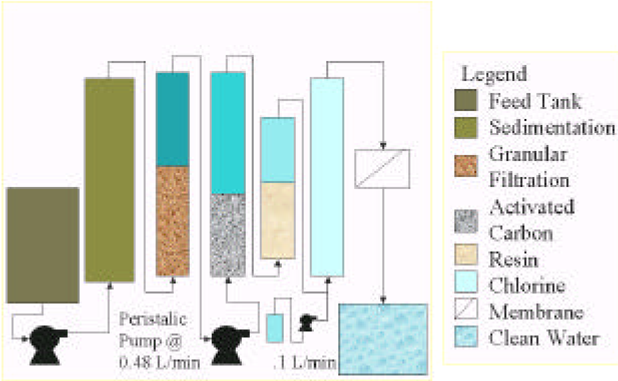

Figure 1: Process Diagram of Water Treatment Plant

MATERIALS AND ASSEMBLY

All reactors were constructed from plexiglass (6-inch diameter with a height of 4-feet). Tygon tubing and Cole Parmer peristaltic pumps were used to control flowrate.

A peristaltic pump feeds the raw water into the sedimentation column from the bottom to avoid any disturbance of the settling particles. The filter media consists of 4-inches of 1-inch limestone, 6-inches of ½-inch limestone, 4-inches of 10-mesh sand and 4-inches of 20-mesh sand. Since the sand media is lightweight, 1-inch of 1-inch limestone was placed on top of the sand to keep it from floating to the top of the column as water flows up. The activated carbon used is 600-grams of Calgon F-400 Granular Activated Carbon with a 12 mesh size. Since the carbon is also lightweight, 1-inch of 1-inch limestone is placed on top of the carbon bed to keep it from floating to the top of the column. 500-grams of Purolite Cation Exchange Resin is used in the cation exchange resin column for softening. The chlorine solution used for disinfection was 0.25-mL of commercial laundry bleach per 10-L of DI (deionized) water. A brealthrough curve was generated to obtain chlorine dosage. This is presented in Figure 2.

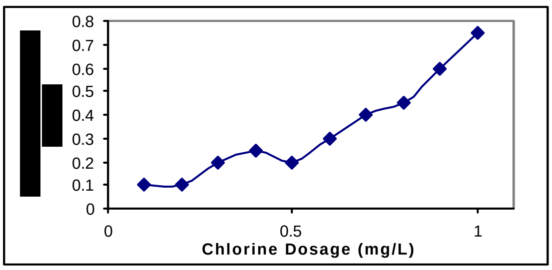

Figure 2: Breakthrough Curve for Cholorine Dose

A peristaltic pump feeds the chlorine dose into the disinfection column at a flow of 0.8 to 0.1 L/min. The required chlorine dosage added to the column is 0.6 mg/L. The feed tubing is tee'd into the feed line, which connects the outlet of the ion exchange resin column to the chlorine disinfection column. This is illustrated in Figure 3.

Figure 3: Chlorine Pump Connection

Plumbers' sanitation fittings were used for all connections. A typical sampling port at the outlet of each column is shown in Figure 4. The removable access ports on each of the columns was tapped and fitted with a 3/8" npt, ¼" barb fitting. Glass wool was placed on the inside of the access ports to prevent column media from exiting with the effluent.

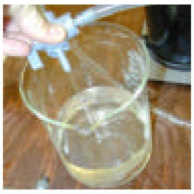

Figure 4: Typical sampling port

The entire plant was placed in a 2-ton pneumatic wheel cart (C&H Supply). To hold up the columns, a superstructure above the cart using steel runners was constructed. To provide lateral support, a hole for each column was bored in a solid piece of plywood, which would rest on the top shelf of the cart (Figure 5).

Figure 5: Upper Mounting System for Reactors

The support system for the reactors underneath the cart bottom is illustrated in Figure 6.

Figure 6: Cart bottom shelf showing how columns are held laterally in place

After the columns were given a support structure on the cart, 4" plumbing fittings were permanently affixed to the plexiglass columns with standard plumber's cement. The entire lab-scale finished plant is illustrated in Figure 7.

Figure 7: Pilot Scale Water Treatment System

PLANT PERFORMANCE

The plant was successfully operated to treat Rowan Pond water to certain drinking water standards. Water quality parameters were monitored from the effluent of each unit process. The values of the monitored water quality parameters exiting from each process are presented in Table 2.

The cost for the entire plant was $2,500. The total weight of the plant was 500 lbs with a footprint area of 11ft^2 (4'x 2.75') and a height of 6.5 feet. Standard laboratory equipment such as turbidimeters, titrators, pH meters, conductivity meters, spectrophotometers were used for water quality analyses. Local vendors donated all reactor media. The plant was successful in generating enthusiasm and excitement in courses such as Water and Wastewater Treatment and Design and Unit Operations. Laboratory evaluations indicated that students' understanding of various unit operations in a realistic setting was enhanced by the ability of visualizing treatment operations. The clinic team also benefited from the project in terms of better understanding of project management, engineering design, unit operation principles and teamwork. Students also strengthened their communication skills through technical writing and oral presentations.

Table 2: Water Treatment Parameters Results

Parameters	Conductivity microseimens	pH	Hardness (mg/L)	Turbidity (NTU)	Nitrate (mg/L)	Bacteria
Raw water	811	6.33	100	6.2	3	Positive
Sedimentation	800	6.44	100	15	N/A	Positive
Sand Filtration	859	7.12	50	16	N/A	Negative
GAC Adsorption	850	6.91	50	2.5	3	Negative
Ion Exchange	891	7.51	20	2.48	N/A	Negative
Disinfection	694	7.19	15	2.43	3	Negative

Note: N/A (not applicable)

CONCLUSIONS

A cost effective lab-scale water treatment plant was successfully developed. Visual observations along with water quality measurements helps in better understanding of treatment processes in chemical and environmental engineering. Course evaluations indicate that students have a better understanding of the design of a water treatment plant and its unit operations.

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